(12) UK Patent Application (19) GB (11) 2 310 765 (13) A

(43) Date of A Publication 03.09.1997

(21) Application No 9604474.8

(22) Date of Filing 01.03.1996

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(51) INT CL[6]
H01F 38/14 , H04B 5/00

(52) UK CL (Edition O)
H1T T1C T12 T7C1A
H4L LCX L1CX

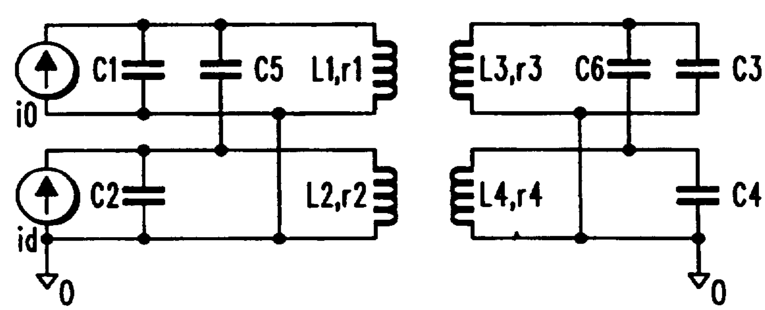
(56) Documents Cited
EP 0509125 A1 **US 5329274 A** **US 4428078 A**

(58) Field of Search
UK CL (Edition O) **H1T**
INT CL[6] **H01F 38/14 , H04B 5/00**
ONLINE: WPI

(54) Inductively connected coils with a capacitive coupling arrangement

(57) A system in which a reader (1) and a data carrier device (2) each have power (L1, L3) and data (L2, L4) coils for inductively communicating power and data, undesired cross-coupling between the coils (L1, L2) of the reader and/or the coils (L3, L4) of the data carrier device is reduced by the provision of capacitive coupling (C5, C6) between the coils of the reader and/or the coils of the data carrier device.

FIG. 5



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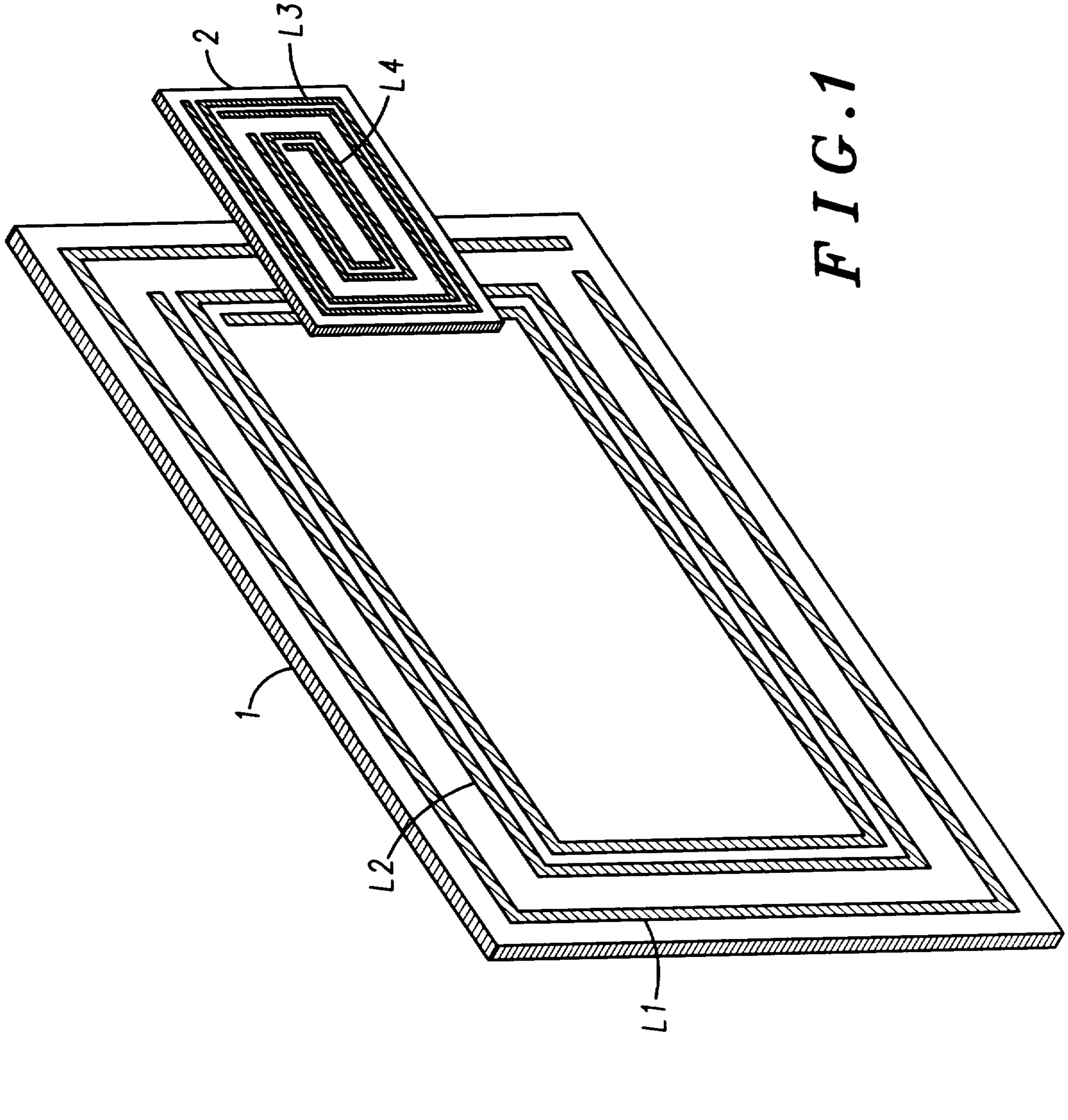
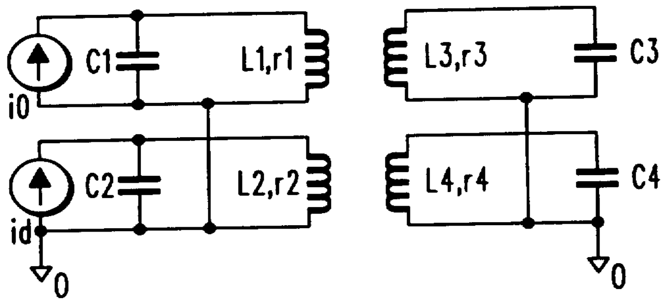
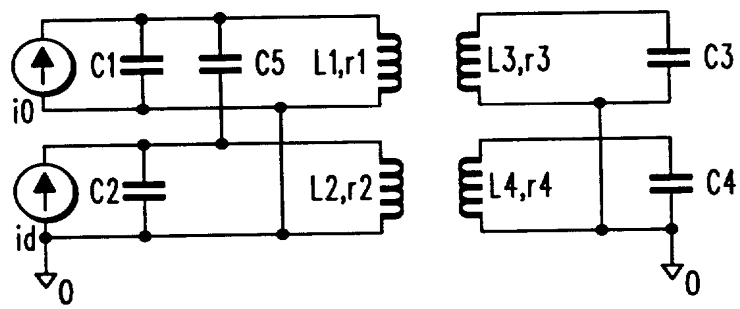


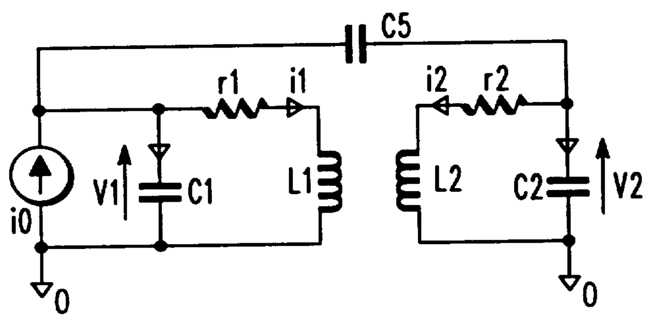
FIG.1



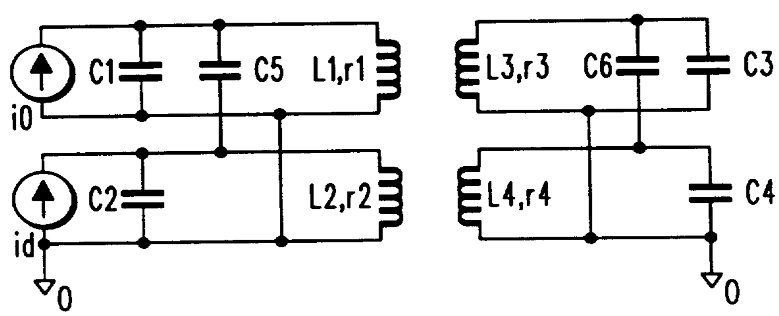
F I G . 2



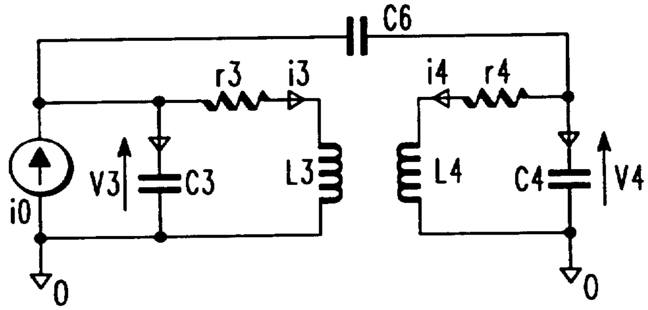
F I G . 3



F I G . 4



F I G . 5



F I G . 6

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DATA CARRIER DEVICE, TERMINAL AND SYSTEM

FIELD OF THE INVENTION

This invention relates to a system incorporating one or more data carrier devices, and particularly to a system employing data carriers which communicate with terminals or readers by inductive coupling.

BACKGROUND OF THE INVENTION

In a system employing data carriers such as contactless cards (commonly referred to as "smart cards") a fixed station (commonly referred to as a terminal or reader) is used to communicate with one of many smart cards carried by potential users. Power and data are transmitted from the reader to the card and data is returned from the card to the reader. Typically, and in the case considered herein, the coupling between the reader and the card is of inductive nature for both power and data.

In many known systems a signal at a first carrier frequency is used to transmit power to the card and a signal at a second carrier frequency is used to transmit data in the two directions. The power carrier frequency in such systems may lie in one of certain narrow band channels, within which particularly high levels of radiated power are tolerated. The data signal, which occupies too wide a bandwidth for these channels, is transmitted at another frequency and a much lower level.

It will be understood that, in these circumstances, the reader and card each require two tuned coils, a first coil tuned to the power carrier frequency and a second coil tuned to the data carrier frequency. It is advantageous to make each coil as large as possible to increase the coupling between the reader and card and to maintain adequate coupling within a large operating space. It is essential, furthermore, that adequate coupling be simultaneously obtained for both the power and data carriers, as the card is typically devoid of energy storage which would permit data to be received or transmitted for useful periods in the absence of a power supply.

The constraints of large pairs of coils and simultaneous coupling lead to the adoption of geometries with significant inductive coupling between the coils of the reader and between the coils of the card. This coupling is deleterious to the performance of the system. In the reader it produces a current at the power frequency in the data coil which reduces the power carrier field strength , and thus reduces the efficacy of the power transfer to the card. In the card it causes the data signal to be contaminated by an undesirable component at the power carrier frequency.

The effects are consequent. While the power carrier field will be reduced throughout the normal operating (i.e., inductive communicating) zone of the card it will be little affected very close to the reader power coil. The current permitted in the coil may, however, be limited by restrictions on the maximum field strength anywhere, for example, so as to limit human exposure to the magnetic field. Thus it may not be permissible to counteract the reduction in the field strength in the working zone by simply increasing the power coil current.

The data signal being wide-band must often be transmitted at much lower level that the power carrier. The power frequency signal coupled from the card power coil to the card data coil may then readily exceed the data signal itself.

It is an object of the present invention to sensibly reduce these deleterious effects.

SUMMARY OF THE INVENTION

In accordance a first aspect of the invention there is provided data carrier device as claimed in claim 1.

In accordance with a second aspect of the invention there is provided a terminal as claimed in claim 4.

In accordance with a third aspect of the invention there is provided a data carrier device and terminal system as claimed in claim 7.

BRIEF DESCRIPTION OF THE DRAWINGS

One card, reader and system in accordance with a preferred embodiment of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Fig. 1 shows the arrangement of power and data coils of a card and a reader of the system;

Fig. 2 is a schematic circuit diagram which shows a four coil transformer model of the arrangement of Fig. 1;

Fig. 3 is a schematic circuit diagram which shows a four coil transformer model, similar to Fig. 2, with reader coil cross-coupling cancellation;

Fig. 4 is a schematic circuit diagram which shows a simple transformer model of the reader coils of Fig. 3;

Fig. 5 is a schematic circuit diagram which shows a four coil transformer model with reader coil cross-coupling cancellation and card coil cross-coupling cancellation; and

Fig. 6 is a schematic circuit diagram which shows a simple transformer model of the card coils of Fig. 5.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

A reader, 1, having a power transmitting coil L1, and a data coil L2, and a card, 2, having a power receiving coil L3 and a data receiving coil L4 is shown symbolically in Fig. 1. The coils will all be tuned to the appropriate respective frequencies to optimise the coupling between the reader and card. Each coil will be coupled inductively to each other coil. The arrangement is therefore characterised by four inductances and six coupling factors. The coupling factor between L1 and L2 being designated k_{12} etc.. It will be assumed that the coils will be dimensioned so that coupling via stray capacitance is negligible.

The reader and card can be modelled by the four coil transformer arrangement shown in Fig. 2. Here, in addition to the coils and coupling factors the losses of the coils or other elements are represented by effective coil series resistors r1 etc. and the tuning capacitors are shown as C1 etc. For simplicity, without loss of generality, the reader power coil is shown excited by a sinusoidal AC source at the chosen power carrier frequency and the reader coils, likewise, the card coils are assumed to share a common reference terminal.

It will be understood that the excitation will establish a large circulating current in the reader power circuit L1, C1, r1 which, as explained, will be resonant at the power carrier frequency. It will also be understood from Fig. 1 that the inductive field thereby produced will couple to the reader data coil L2, the degree of such coupling depending purely on the geometry of the coils and being represented by the coupling factor k_{12}. It will be understood that in the analyses which follow the subscripted variables L_1, C_1, r_1, etc. respectively represent the inductance, capacitance, resistance, etc. of the coil L1, capacitor C1, resistance r, etc.

Due to the inductive coupling a sinusoidal current at the power carrier frequency will tend to flow in the data coil circuit L_2, C_2, R_2. This current will flow in a sense which tends to cancel the inductive field coupled to the data coil and thus to reduce it throughout the zone within which the card may lie.

Fig. 3 shows the system modified, in accordance with the present invention by the addition of a fifth capacitor, C5, providing an additional coupling path between the reader power and data coils.

As will be shown analytically below, this capacitor C5 serves to couple from the power coil to the data coil a current which is out of phase with, and so substantially cancels, the power carrier current inductively coupled into the data coil. Thus the capacitor C5 serves to restore the inductive field to essentially the value it would have were no reader data coil present.

For this purpose of this analysis it will be assumed that the card is far away from the reader, so that the only significant inductive coupling is that directly between the reader coils. Should the card be close enough to invalidate this assumption there would be no practical need to preserve the field strength.

The reader alone can be modelled by the simple transformer of Fig. 4, which includes the additional capacitor C5.

By inspection we may write the Laplace transform equations for the voltage and current relationships in the usual manner, using mutual inductance ($M = k_{12}\sqrt{L_1L_2}$) to represent the coupling to simplify the notation.

$$v_1 = i_1(r_1 + sL_1) + i_2sM_{12}$$
$$v_2 = i_2(r_2 + sL_2) + i_1sM_{12}$$
$$i_0 = i_1 + v_1sC_1 + (v_1 - v_2)sC_5$$
$$i_2 = (v_1 - v_2)sC_5 - v_2sC_2$$

Note that the sign of the mutual inductance in these equations is determined by the sense of the coil windings. It is assumed that they are wound in the same sense starting from the active terminals and finishing at the common reference terminals.

By straightforward algebraic manipulation we may obtain an expression for the current in the data coil:

$$i_2 = \frac{si_0\{r_1C_5 + s[C_5(L_1 - M_{12}) - C_2M_{12}]\}}{A_{(s)}}$$

The denominator is a long fourth order expression which need not be expanded for the purpose of this discussion. The effect of the additional capacitor C5 is demonstrated in the numerator. Without this capacitor the numerator would be:

$$-s^2C_2M_{12}i_0$$

By choosing: $$C_5 = C_2 \frac{M_{12}}{(L_1 - M_{12})}$$

we may cancel the term. Adding C5 introduces the residual term in r_1C_5 but r_1 is the loss resistance which is very small. Typically the current is reduced by two orders of magnitude.

It will be apparent that if the sense of the winding of one coil is changed then M will become negative and the inductive coupling will not be cancelled by the capacitive coupling.

If there is little current in the data it follows that the field due to the current in the power coil will be near its ideal value.

In the model shown the power coil will be tuned by the capacitance C_1, in parallel with the series combination of C_2 and C_5. The residual current in L_2 increases the losses in the power coil resonant circuit and in practice other losses due to the interface to the data coil driver etc. will also influence the Q of the power circuit. The effects are of secondary importance. As explained earlier it is current in the reader power coil which may be restricted, not the power required to produce it.

Fig. 5 shows the system further modified, in accordance with the present invention, by the addition of a sixth capacitor, C6, providing an additional coupling path between the card power and data coils.

As will be shown analytically below, this capacitor C6 serves to couple from the power coil to the data coil a voltage which is out of phase with, and so substantially cancels, the power carrier voltage inductively coupled across the data coil terminals. Thus the capacitor C6 serves to restore the voltage inductively coupled across the data coil terminals to essentially the value it would have were no power carrier present.

It will now be shown, analytically, that this capacitor C6 can be adapted to sensibly cancel the power carrier voltage appearing between the data coil terminals. For this purpose of this analysis it will be assumed that inductive coupling between the card power and data coils is the

predominant means by which such a voltage may be produced. This assumption is normally valid because, while the coupling factors between the reader power coil and the two card coils are likely to be similar the coupling between the card coils will be much higher and the current circulating in the card power coil is amplified by resonance. It is impractical to cancel the combined power signals in the data coil because the Q of the power circuit will vary according to the load imposed by the powered circuits.

Since the coupling from the reader power coil to the card data coil will be neglected the card can be considered alone and modelled by the simple transformer of Fig. 6, which includes the additional capacitor and where the power coil excitation is represented by the current generator, i_0. Fig. 6 will be seen to be identical to Fig. 5 except for the component numbers.

Proceeding as before we may again write the Laplace transform equations for the voltage and current relationships and by algebraic manipulation obtain an expression for the voltage produced between the data coils terminals in response to the excitation by i_0.

$$v_2 = \frac{sM_{34}i_0}{B_{(s)}}\left\{1 + \frac{r_3r_4C_6}{M_{34}} + \frac{sC_6(r_3L_4 + r_4L_3)}{M_{34}} + \frac{s^2C_6(L_3L_4 - M_{34}^2)}{M_{34}}\right\}$$

The form of the denominator is identical to that of the previous case and more detailed explanation of which is not necessary to the discussion. The effect of C_6 is demonstrated in the numerator, which here is second order. It will be evident to those familiar with such expressions that a notch may be produced at a desired angular frequency, ω, by choosing C_6 such that:

$$C_6 = \frac{M_{34}}{\omega^2(L_3L_4 - M_{34}^2) - r_1r_2} \sim= \frac{M_{34}}{\omega^2(L_3L_4 - M_{34}^2)}$$

Adding C_6 introduces the residual term:

$$v_2 = \frac{s^2C_6(r_3L_4 + r_4L_3)i_0}{B_{(s)}}$$

but this is substantially below the uncompensated level.

More complete analysis shows that nulling the inductive coupling in the manner described also increases the voltage across the power coil.

CLAIMS

1. A data carrier device for use with a terminal, the data carrier device comprising: power coil means for receiving from the terminal an inductively coupled power signal; data coil means for receiving from the terminal and transmitting to the terminal an inductively coupled data signal; and capacitive coupling means between the power coil means and the data coil means for reducing inductive cross-coupling of signals in the power coil means and the data coil means of the data carrier device.

2. A data carrier device as claimed in claim 1 wherein the capacitive coupling means is arranged to minimise the voltage in the data coil means at the frequency of the power signal which appears in the data coil means.

3. A data carrier device as claimed in claim 2 wherein the capacitive coupling means has a capacitance substantially equal to $\frac{M}{\omega^2(L_P L_D - M^2)}$, where M is the mutual inductance between the data coil means and the power coil means, L_P is the inductance of the power coil means, L_D is the inductance of the data coil means, and ω is a desired operational frequency.

4. A terminal for use with a data carrier device, the terminal comprising: a first coil for transmitting to the data carrier device an inductively coupled power signal; a second coil for receiving from the data carrier device and transmitting to the data carrier deviation inductively coupled data signal; and capacitive coupling means between the first and second coils for reducing inductive cross-coupling of signals in the first and second coils of the terminal.

5. A terminal as claimed in claim 4 wherein the capacitive coupling means is arranged to minimise the current in the data coil means at the frequency of the power signal which appears in the data coil means.

6. A data carrier device as claimed in claim 5 wherein the capacitive coupling means has a capacitance substantially equal to $C_D \frac{M}{(L_P - M)}$, where CD is a tuning capacitance associated with the data coil means, M is

the mutual inductance between the data coil means and the power coil means, and L_P is the inductance of the power coil means.

7. A system having at least one terminal and at least one data carrier device,
the data carrier device comprising: a first coil for receiving from the terminal an inductively coupled power signal; a second coil for receiving from the terminal and transmitting to the terminal an inductively coupled data signal; and capacitive coupling means between the first and second coils for reducing inductive cross-coupling of signals in the first and second coils of the data carrier device; and
the terminal comprising: a first coil for transmitting to the data carrier device an inductively coupled power signal; a second coil for receiving from the data carrier device and transmitting to the data carrier deviation inductively coupled data signal; and capacitive coupling means between the first and second coils for reducing inductive cross-coupling of signals in the first and second coils of the terminal.

8. A data carrier device substantially as hereinbefore described with reference to the accompanying drawings.

9. A terminal substantially as hereinbefore described with reference to the accompanying drawings.

10. A data carrier device and terminal system substantially as hereinbefore described with reference to the accompanying drawings.

The Patent Office

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Application No: GB 9604474.8
Claims searched: 1 - 10

Examiner: John Watt
Date of search: 3 May 1996

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): H1T; H4L (LADA, LCX)

Int Cl (Ed.6): H01F 38/14; H04B 5/00

Other: ONLINE: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	EP 0509125 A1	(SIEMENS) see capacitor 8 in figure 1	1, 4 & 7
&	US 5329274	(SIEMENS) see capacitor 8 in figure 1	1, 4 & 7
X	US 4428078	(BOEING) see figure 6 and line 47 of col. 6 to line 14 of col. 7	1, 4 & 7

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